Creating a Scale for Ionospheric Disturbance

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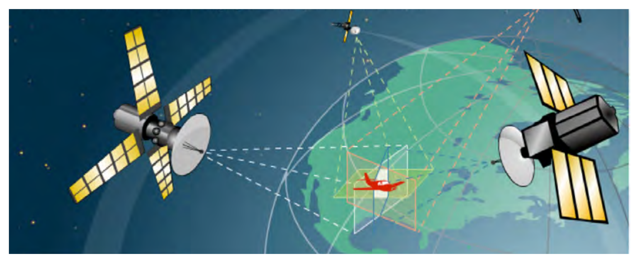
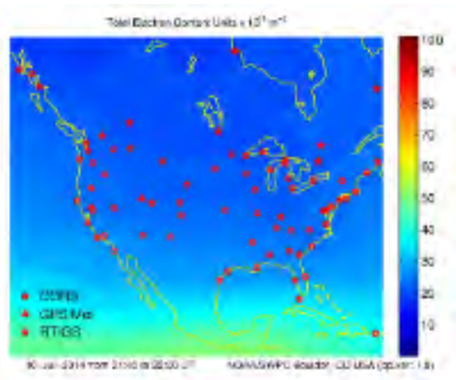
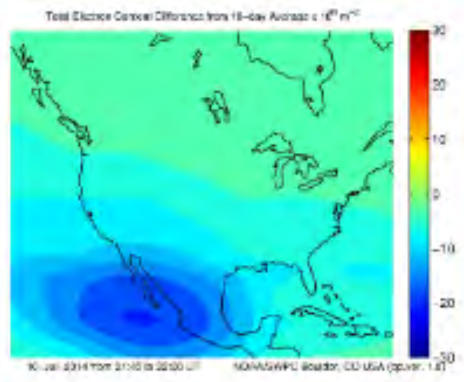
Background:



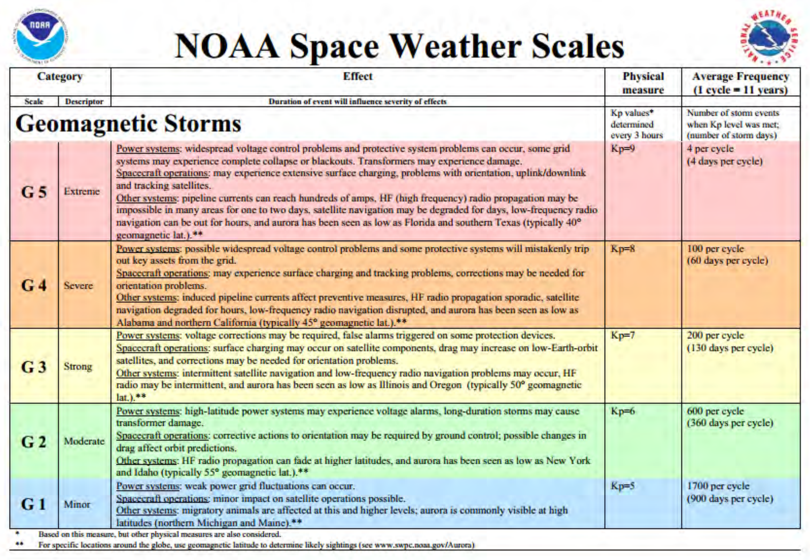
Current GPS technology uses satellites orbiting earth, sending a radio frequency, to triangulate a receiver. These signals sent to the receiver are send through the ionosphere. This causes a diffraction of the signal that is corrected for by the receiver but during periods of geomagnetic disturbance the composition of the ionosphere is not constant and therefore diffracts the signal in an unpredictable way depending on the electron content of the ionosphere between the satellites and receiver. This delay of signal causes greater error in position that can be corrected for by extending triangulation time given that the poor ionospheric conditions are known.





US TEC maps show the total electron content (TEC) of the ionosphere at a given position with a 15 minute cadence. Using this data in combination with Kp values, a measurement of geomagnetic disturbance, and TEQC we differentiated between good and poor ionospheric conditions for operating GPS.

Current scaling systems include NOAA scales for Geomagnetic Storms, Solar Radiation Storms, and Radio Blackouts with the Geomagnetic Storm warning based on the Kp value which is measured every 3 hours from world-wide monitors. The K values from each center are entered into an algorithm to find the planetary K value, Kp. We another NOAA Space Weather Scale to allow GPS users to correct for error caused by ionospheric disturbances.


NOAA Space Weather Scales

Geomagnetic Storms

Category	Effect	Physical measure	Average Frequency
G 5 Extreme	[illegible]	Kp=9	[illegible]
G 4 Severe	[illegible]	Kp=8	[illegible]
G 3 Strong	[illegible]	Kp=7	[illegible]
G 2 Moderate	[illegible]	Kp=6	[illegible]
G 1 Minor	[illegible]	Kp=5	[illegible]

Abstract:

The relationship between the vertical total electron content (VTEC) and geomagnetic conditions was studied in order to develop a scale informing GPS users of position errors associated with ionospheric disturbances. We have attempted to differentiate between good and poor GPS conditions illustrated by the departure of TEC values from a 10 day running average (trend) based on geomagnetic conditions characterized by the Kp index. We found no useful correlation between CONUS vertical TEC averages or CONUS trend averages, and Kp. This points to the need of a position dependent index, i.e. a map of GPS errors as a function of time, instead of a global number.

Methods:

We considered Kp indicies as a possible indicators for poor ionospheric conditions. We did this by comparing relative TEC to the K value during each time period. We initially plotted relative TEC as a scatter plot for a ten day period with quiet, unsettled, and disturbed Kp values in different colors. We also plotted days which were mostly quiet or mostly disturbed. In this comparison we found that the CONUS trend averages for TEC during time periods with a Kp index in the disturbed range had a wider spread for relative TEC than time periods with a Kp index in the quiet range. However, as more days were considered the difference between disturbed and quiet conditions shrank so there appears to be no separation between the two.

Kp index:

The CONUS vertical TEC average and CONUS trend averages were plotted as functions to time with each point a different color depending on the planetary K value during the time period.

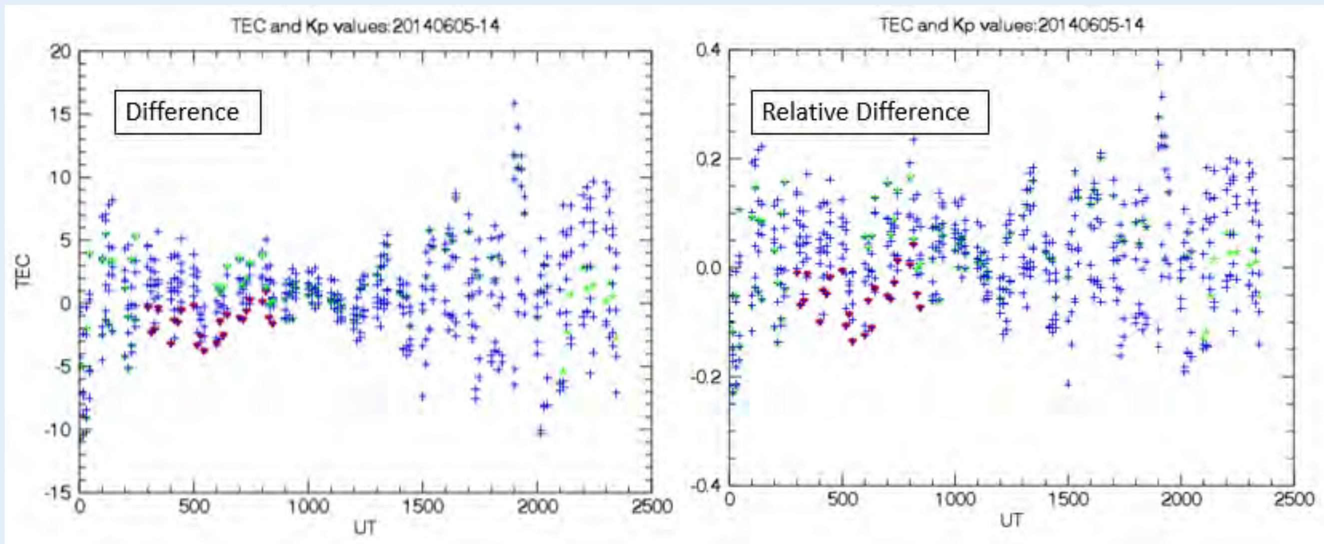


Figure 1:
These plots are for a ten day time period with blue point indicating geomagnetically quiet conditions (Kp less than 3), green points indicating unsettled conditions (Kp between 3 and 5), red points indication disturbed conditions (Kp greater than 5).

There was little correlation between geomagnetic disturbance and the relative TEC. We looked at 10 period time frames and also days with the most extreme Kp values.

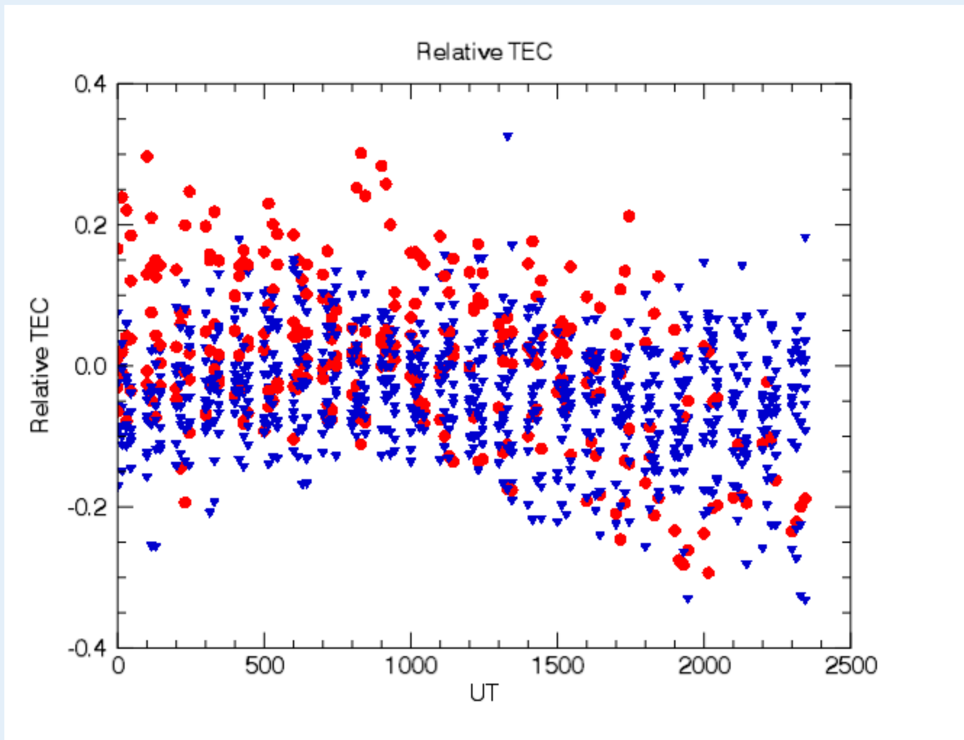


Figure 2:
While originally the quiet and disturbed time periods had been separated, with the disturbed spanning a wider band, as more time periods were sampled the two sets were no longer different.

sTEC:

We then looked to find a position dependent disturbance index by taking the difference between the return time for satellite signals for two different positions of the satellite with a step size of 30 seconds.

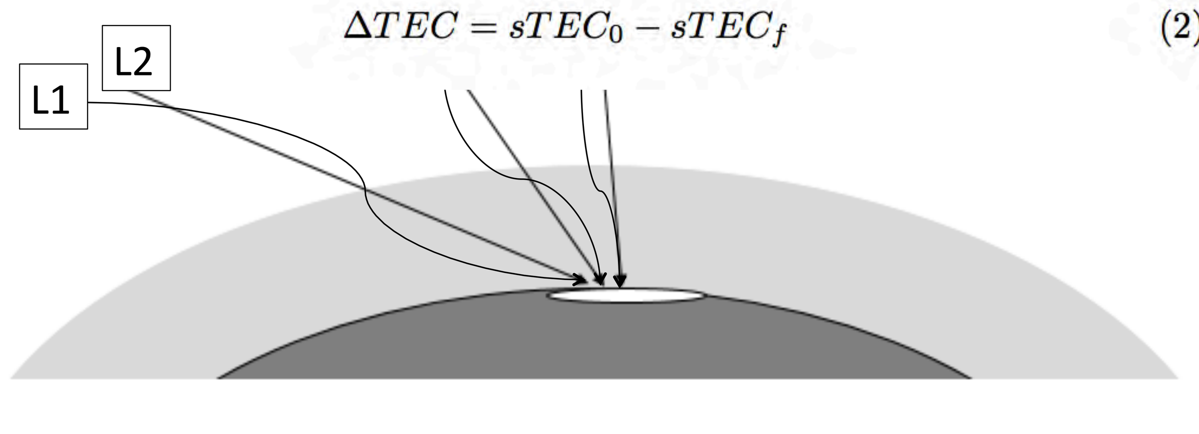
Disturbance Index:

$$sTEC = 9.52 \cdot (L1 - L2) \quad (1)$$

The GPS carries signals with different frequencies. The receiver on the ground counts the number of times the signal goes through zero with the following frequencies:

$L1$	1575.42 MHz
$L2$	1227.6 MHz

$$\Delta TEC = sTEC_0 - sTEC_f \quad (2)$$



When we plot sTEC we get a parabola, with vertical TEC represented by the minimum. This is because the signal is going through the minimum amount of ionosphere when it is transmitting vertically.

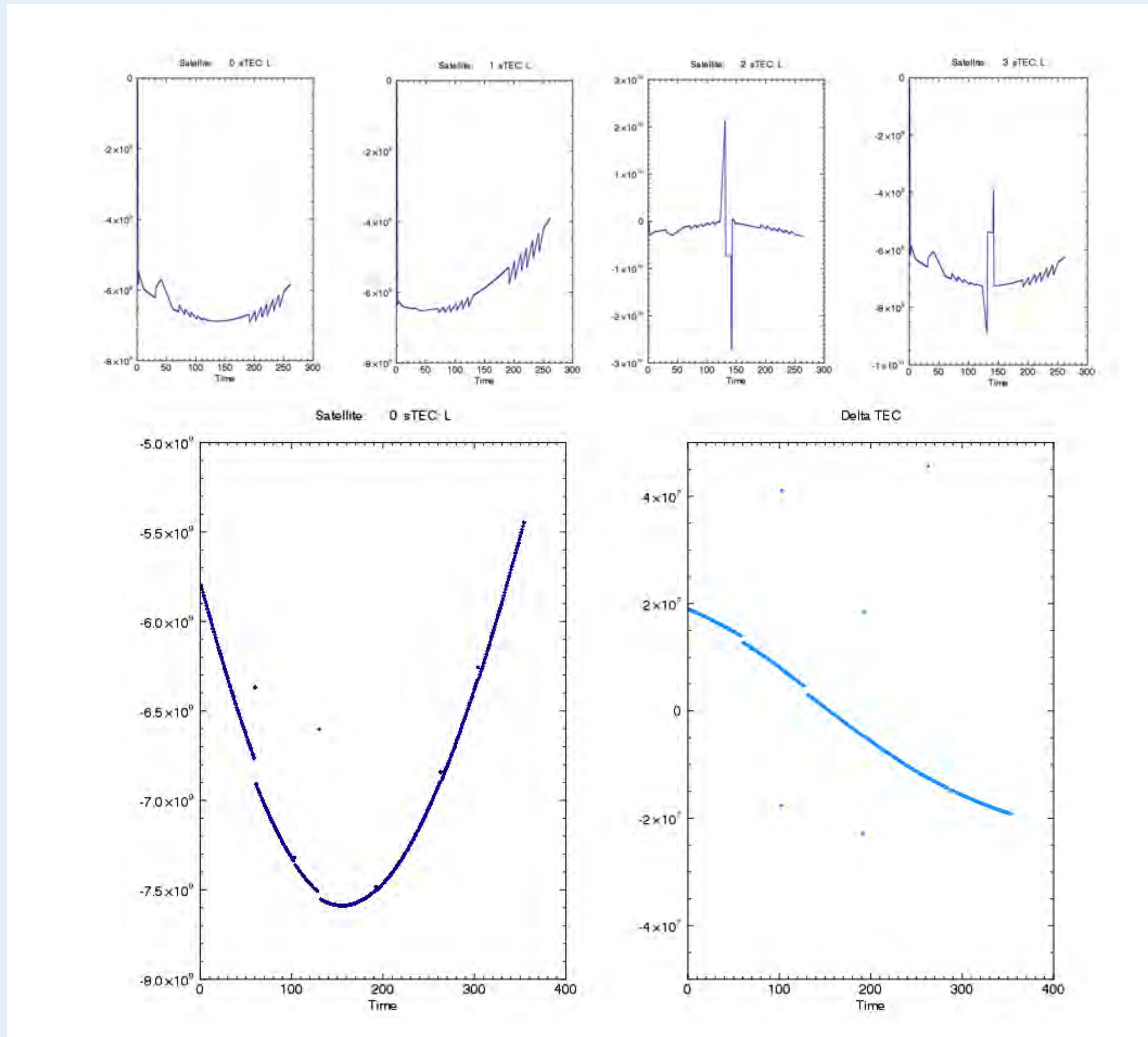


Figure 3:
The top four plots demonstrate the curve generated by the sTEC from a two hour data set with quite a few missing times. The lower plots are sTEC for a four hour time frame on the left, and the difference from the previous time step on the right.

Results:

In the study of the relationship between the vertical total electron content (VTEC) and geomagnetic conditions we found no useful correlation between CONUS vertical TEC averages or CONUS trend averages, and Kp. This points to the need of a position dependent index, i.e. a map of GPS errors as a function of time, instead of a global number.

This makes sense as the TEC is seem to vary on USTEC plots based on position. While large areas have comparable TEC for quiet conditions, as solar storms begin the TEC become much more position dependent.

Future Work:

In attempting to classify TEC we looked to how the vertical electron count changed over our three years worth of data and found that over the course of a year it behaves sinusoidally. This is useful in prediction and creating a scale because it acts as a background for our scaling system.

This, in conjunction with current physics models for TEC prediction will be combined to form a better tool for predicting Ionospheric conditions and classifying them by a deviation from average.

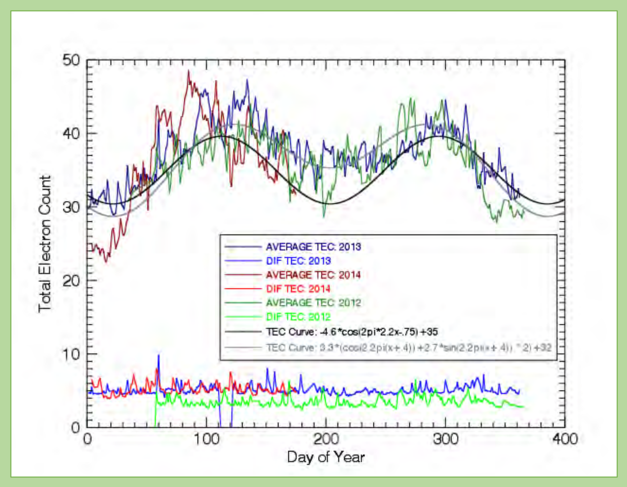


Figure 4:
This plot demonstrates the seasonal TEC average variation which behaves sinusoidally as a function of time.

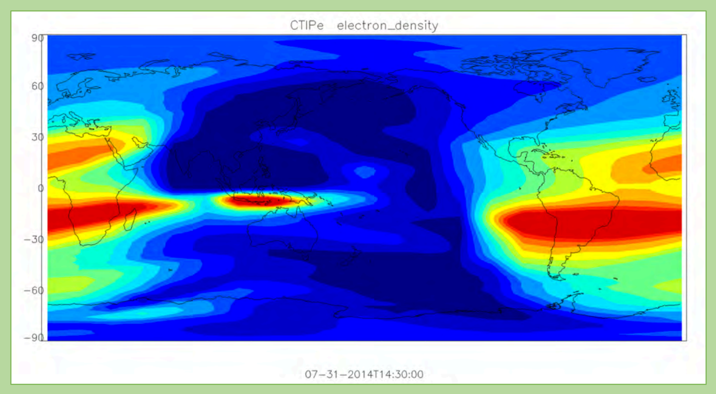


Figure 5:
This is a current physics based model for TEC which runs in real-time.

Once Ionosphereic conditions can be classified by looking at the TEC we will incorporate the signs for large GPS into a model that will have real-time TEC as well as being predictive.